I N S T R U C T I O N   M A N U A L

MODEL 1000 CURRENT INTEGRATOR

Maintenance and Operating Instructions

BROOKHAVEN INSTRUMENTS CORPORATION

Brookhaven, New York

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MODEL 1000 CURRENT INTEGRATOR SPECIFICATIONS

Input Characteristics

Polarity: selected by switch on front panel.
Ground: isolated from case.
Voltage drop: less than .1 microvolt on all ranges.
Current Indication: panel meter, 1% accuracy.
Current Range: 0 to 20 ma in 15 ranges as follows:

Range	F. S. Amperes	Input Averaging Time 1 sec. mode	Input Averaging Time .01 sec. mode
1	$2x10^{-2}$	10^{-3}	.01
2	$6x10^{-3}$	$3x10^{-3}$	.01
3	$2x10^{-3}$	10^{-2}	.01
4	$6x10^{-4}$	$3x10^{-2}$	.01
5	$2x10^{-4}$	10^{-1}	.01
6	$6x10^{-5}$	$3x10^{-1}$	.01
7	$2x10^{-5}$	1	.01
8	$6x10^{-6}$	1	.01
9	$2x10^{-6}$	1	.01
10	$6x10^{-7}$	1	.01
11	$2x10^{-7}$	1	.01
12	$6x10^{-8}$	1	.01
13	$2x10^{-8}$	1	.01
14	$6x10^{-9}$	1	.01
15	$2x10^{-9}$	1	.01

Digitizing Accuracy (Absolute)

Typically .02% F.S. .05 guaranteed on all ranges.

Reproducibility

± .001% on 1st 10 ranges, gradually increasing to ± .01% on range 15.

Offset Adjust: ± 10% of F.S. current. Offset current is regulated to .01% F.S.

Peak Pulse Input Current: 20 ma on all ranges.

Digital Output

Unit of Charge: F.S. current x 10^{-2} sec.
Frequency: 100 pps for F.S. current.
Output Pulse: Optional length, voltage, polarity (50 to 100 ohm load required).
Automatic Dead Time Correction: 5 to 10V pos. signal inhibits output pulses, 50 nsec resolution.

(Specs continued on next page)

(Specs cont'd)

Mechanical

Metal enclosure 7" x 17" with standard 19" relay-rack panel.

Additional Features

All solid state.
Front panel control converts integrator to microvoltmeter for input circuit balancing.
Reset: momentary circuit break provided to clear external counter when integrator reset button is operated.
Input and output connections accessible at front and rear of enclosure.
Output provided for driving remote current indicating meters.

EXTERNAL CONNECTIONS

The live and ground sides of the input current source should be connected to the "Hi" and "Lo" input terminals respectively. The "Lo" terminal may be connected to the case with the link provided on the binding post assembly or it may be left open to avoid creating a ground loop if the input cable sheath is grounded at some other point.

The "Hi," "Lo" and "Case" terminals are available on the rear terminal strip as terminals 6, 7 and 5 respectively.

The digital output pulses may be applied to the counter input via the BNC connector at the front or rear of the chassis as desired. The cable to the counter should be terminated. A 50 or 75 ohm cable is satisfactory.

External current indicating meters may be connected to terminals 3 and 4 of the rear strip as shown on fig. 1. Dc meters of 1.0 ma sensitivity are required. Any desired number of meters may be connected in series. To allow for variations in meter resistance, depending upon the number and type of meters used, the internal meter multiplier resistor is chosen to make the external meters read about 15% high with no additional resistance in the circuit.

$100 \times 10^{-6} \times 100 \times 10^{3}$

10000×10^{-3} 10^{3}

When external meters are connected an external series resistor should be included as shown in fig. 2. The resistance must be adjusted to make the external meter readings agree with those of the meter on the panel. The resistance required will be about 1.5K. If desired, a 2.5K potentiometer can be inserted in the circuit and locked when the correct adjustment is reached.

Alternatively a 100μa external meter may be used with an additional 100K series resistance. Part of the 100K resistance may then be shorted momentarily to provide high sensitivity without switching ranges for preliminary tuning of accelerators, etc.

Terminals 1 and 2 on the rear strip provide a normally-closed circuit which is momentarily opened when the Reset button is pressed. The reset line of the external counter may be connected through these terminals so that the counter will be cleared when the button is pressed. This circuit is isolated from all circuitry in the instrument and from the case so there need be no concern about introducing ground loops if it is connected to the counter ground.

OPERATING PROCEDURE

*The Averaging Time switch (rear of chassis) should be set in the desired mode. The adjustments for operation must then be made in the following order:

1. Amplifier Zero

For this adjustment the Polarity Switch may be in either position and the range switch on any range. Place the Function Selector in the "amplifier zero" position and carefully adjust the Amplifier Zero control so that the panel meter reads zero. This adjustment is quite stable and normally need be made only once if the control is not subsequently disturbed. It is not affected by switching ranges.

* Normally the 1 sec position is used only for the integration of pulses.

2. Input Balance

The Polarity and Range switches must be set for the desired operating conditions, the target connected to the integrator input circuit and no beam applied. The Function Selector should be placed in the "operate" position and the Input Balance control adjusted until the meter reads zero. The input circuit is now roughly balanced.

The Function Selector should now be placed in the "input balance" position and the Input Balance control carefully adjusted until the meter again reads zero. In this position the residual input error is greatly magnified and the adjustment will be quite critical.

On the 2 or 3 lowest ranges, transistor noise in the amplifier input circuit may cause the meter to fluctuate somewhat. In this case the Input Balance control should be set so that the fluctuations on either side of zero are equal.

3. Operate

The Function Selector should next be placed in the "operate" position. The instrument is now ready for operation. If the switch is left in the "operate" position for more than one minute before the beam is turned on, the Reset button should be pressed just prior to integration to remove any accumulated charge in the integrator capacitor which could cause an initial error of several counts. Pressing the Reset button will also clear the counter if its reset circuit is connected to terminals 1 and 2 on the rear terminal strip. If it is desired to preserve the counter content the integrating capacitor can be discharged by switching the Function Selector switch momentarily to the "input balance" position. When the Averaging Time switch (rear of chassis) is in the "1 sec" position the counter will be observed to register counts for a few seconds after the input current ceases. These counts represent part of the integrated charge and should be allowed to register before the counter is turned off.

AUTOMATIC DEAD TIME CORRECTION

For automatic dead time correction the digital output can be inhibited by a +5 to 10V signal applied to the "inhibit" connector. In even a comparatively short integrating period many thousands of output pulses will occur. The proportion of the output pulses inhibited by dead time signals of random length and interval will, therefore, be essentially equal to the proportion of the integrating period that was occupied by dead time signals.

If the inhibit signal is present when an output pulse is due to arrive the pulse will be blocked but if a dead time signal is applied while an output pulse is in progress that pulse will not be split. The resolution of this gate is less than 50 nsec so that dead time signals as short as 1 μsec will be accurately accounted for.

PULSE INTEGRATION

The Model 1000 Integrator is capable of integrating pulsed input currents, even of very low duty factor, with essentially the same accuracy as dc inputs. For pulse integration the Averaging Time switch (rear of chassis) must be in the "1 sec" position.

The set-up procedure is the same as that for dc operation. Care must be observed, however, to avoid error due to overloading of the input amplifier.

The first precaution is that the peak current, applied to the input on any range, never be permitted to exceed 20 ma.

The second precaution is that the current range be chosen so that the output voltage capability of the input amplifier is not exceeded. The correct current range may be determined analytically or empirically as follows:

Analytical Method: For almost all pulsed input conditions the optimum current range will be the lowest range which will satisfy the following inequality (1):

$$I_{fs} \geqq \frac{Q_p e^t}{e^t - 1} \qquad (1)$$

Where I_{fs} = current range (amperes),

Q_p = charge contained in each input pulse (coulombs),

t = pulse repetition period (seconds),

e = 2.718.

The above expression is valid for all cases where the indicated minimum for I_{fs} does not exceed 2×10^{-5} A. If a value higher than 2×10^{-5} A is indicated then the current range must be chosen to satisfy inequality (2):

$$(2) \qquad I_{fs} \geq \frac{2 \times 10^{-5}}{t} \ln \frac{2 \times 10^{-5}}{2 \times 10^{-5} - Q_p}$$

Empirical Method: The optimum current range for a given pulsed input may be determined by observing the voltage on terminal 4 of the rear terminal strip (external meter disconnected) on an oscilloscope with the pulsed input applied and selecting the most sensitive current range which will not cause the peak voltage to exceed -10V (+ 10V on terminal 3 for negative inputs). The oscilloscope must have dc response so that the total voltage to ground is observed. The oscilloscope ground should be connected to the "Lo" input terminal.

OPERATING PRECAUTIONS

If a fluctuating current is to be integrated it is important to choose a current range higher than the maximum anticipated beam current because input currents in excess of full-scale will not be integrated, resulting in error.

The input circuit is protected by a pair of silicon diodes so that accidental input currents as high as several hundred ma can be tolerated on any range without causing permanent damage to the instrument. Excessively large currents, however, will saturate the input amplifier and charge the chopper filter capacitor, disabling the instrument for several

minutes. If this difficulty occurs, the cure is simply to leave the Function Selector in the "operate" position and wait until the meter settles to zero. A diode feedback network in the input amplifier insures that such saturation will not occur at input currents up to several times full-scale.

The electrical ground ("Lo" input terminal of the integrator) may be connected to the chassis by use of the grounding link at the input terminals or it may be connected to any other point which is nominally at ground potential in the experimental system. Never attempt to apply input current to the integrator with the "Lo" terminal floating.

THEORY OF OPERATION

Symbols used in the following explanation of operation refer to the block diagram, Fig. 2. This diagram is provided for explanatory purposes only and is greatly simplified. Provisions for polarity switching are not shown and the explanation, except where noted, will assume positive input current.

Chopper-stabilized amplifier A_1, together with R_1, the resistive feedback network delivers an output voltage which is proportional to the input current. The output voltage is of polarity opposite to that of the input current and is equal to -10 volts for full-scale positive input on any range. Pulse inputs are averaged by the capacitor C_1 selected by S_1. The input balancing current is applied to the amplifier input via resistor R_2 which is also selected by S_1.

The output voltage of A_1 is read by the panel meter to indicate the input current.

Resistor R_3, capacitor C_2 and amplifier A_2 comprise a Miller integrator which is used to integrate the output voltage of A_1. A_2 also is an inverting amplifier so that the output voltage of A_2 rises for positive currents at the input of A_1. When the output voltage of A_2 reaches about +2 volts the amplitude discriminator "enables" gate 1 and the flip-flop is triggered to the "on" state by the next trigger pulse from the pulse shaper. The switching diode D_1 now passes a precisely controlled 2 ma current to the summing

point of A_2. This current is of opposite polarity to that resulting from the output voltage of A_1 and drives the output of A_2 downward thereby neutralizing the effect of the input signal. The neutralizing current persists for five msec until the next trigger pulse switches the flip-flop to the "off" state. At this time the output of A_2 will be between zero and -2.5 volts depending upon the input current and will begin to rise again if input current is still flowing. Each time the output of A_2 reaches 2 volts the process is repeated. At full scale input the flip-flop switches at every trigger pulse and neutralizing pulses are delivered to the summing point at the rate of 100 per second.

The value of the neutralizing current is determined by R_4 and the voltage of the reference diode Z_1. The duration of each neutralizing pulse is determined by the period of the 200 cycle fork. Since R_4, Z_1, and the fork are all precision, temperature-compensated components, the quantity of charge delivered during each neutralizing pulse is precisely determined.

Each time the flip-flop is switched into the "on" state to produce a neutralizing pulse the blocking oscillator is triggered to produce one digital output pulse.

Both A_1 and A_2 have an output range of $\pm$ 10 volts. When negative inputs are to be integrated the polarities of the amplifier outputs are opposite to those of the foregoing explanation. Under these conditions the panel meter, reference voltage source and switching diodes must be reversed and the positive amplitude discriminator Q_{23} replaced by negative amplitude discriminator Q_{22}. These operations are performed by switching the Input Polarity switch to the "negative" position.

Amplifier Zero

When the Function Selector is in the "amplifier zero" position the input of A_2 is grounded through a resistor (to simulate its normal driving-source impedance), the feedback impedance of A_2 is changed from capacitor C_2 to resistor R_5 and the meter is switched to read the output voltage of A_2. The output of A_2 is disconnected from the amplitude discriminator to prevent the application of neutralizing pulses to the

input of A_2. Under these conditions the output voltage of A_2 will be zero when the amplifier input circuit is properly balanced. The balancing operation is performed by adjusting the Amplifier Zero control, a variable resistor in the collector circuit of the input stage of A_2.

Input Balance

When the Function Selector is in the "input balance" position, the input of A_2 is connected to the output of A_1. Since the feedback impedance of A_2 is again resistive and the meter is still connected to the output of A_2, A_2 now functions as an electronic voltmeter reading the output voltage of A_1. A_1 is chopper-stabilized and its input offset voltage is essentially zero. Its output voltage, however, will generally not be equal to zero because of thermal emf's and possible leakage currents in the external current source. The Input Balance control is adjusted to apply a current of proper polarity and amplitude to compensate for these effects.

When the Function Selector is anywhere but in the "operate" position, the integrating capacitor C_2 is shorted so that when the switch is moved to the "operate" position there is no residual charge in C_2. Even the most minute unbalance in A_2, however, can cause C_2 to become charged if the Function Selector is left in the "operate" position long enough. This is the reason for the previous recommendation that the Reset button be pressed just prior to integration if the Function Selector has been in the "operate" position for more than one minute and very high accuracy is desired. Alternatively, if the external counter reset feature is being used and it is desired not to clear the counter, C_2 may be discharged by switching the Function Selector momentarily to the "input balance" position.

CALIBRATION AND MAINTENANCE

Factors Affecting Calibration

The resistive feedback network mounted on the Range switch determines the current-to-voltage conversion factor of the input amplifier A_1 and therefore the relative sensitivity on each range. All of the resistors used on ranges 1 through 12 are aged, stabilized, wire-wound resistors of .01% tolerance

and are not adjustable. Because of the high values required on ranges 13, 14 and 15 the resistors used on these ranges are low T. C. metal film units. They are trimmed to the exact values required by additional trimming resistors mounted on the board supported by S_1. The metal-film resistors, although of looser initial tolerance than the wire-wound units, possess the same order of stability and should never require adjustment. The trimmers comprise such a small fraction of the total resistance that drifts in their values would produce negligible error.

The temperature-compensated reference diode used to determine the amplitude of the neutralizing current pulses is of the highest obtainable quality. The diode is "burned in" at the factory to eliminate aging effects and to enhance its long-term stability.

The overall drift of the instrument should not exceed a few hundredths of 1% during several years of operation. The current regulator transistor (2N388A, Q29) should not be replaced unless it is known to be defective because changing it could cause a calibration shift as great as .05%.

The overall sensitivity is determined by the setting of the 1K precision trimmer R_{4A}, (see layout drawing). This adjustment affects the sensitivity equally on all ranges. The setting of R_{4A} should not be disturbed unless the means is available to check the digitizing accuracy to the required precision. If a calibration error of greater than .05% is observed, even after several years of use, it is almost certainly due to a component malfunction and calibration adjustment should not be attempted until the underlying fault is corrected. The adjustment of R_{4A} is extremely critical. One turn will change the overall sensitivity by 2%.

Transistor Replacement

With three exceptions, any of the transistors in the unit can be replaced without causing the need for any adjustment. As discussed under "Factors Affecting Calibration," replacing Q29 may cause a slight shift in overall sensitivity. The other two critical transistors are Q6 and Q7 (2N3391A). These transistors need not be specially selected, but if either

Q6 or Q7 is changed the input offset voltage should be checked and adjusted to zero if necessary.

Input Offset Voltage Adjust

A small offset voltage will not cause error in integration because it will normally be compensated by adjustment of the Input Balance control, but if the offset voltage is substantial it may not be possible to balance the input circuit with low values of external resistance across the input.

To make this adjustment, first ground the "Lo" input terminal. Set the Range switch to 2×10^{-7} A and the Function Selector to "operate." Connect a voltmeter from the slider (rear terminal) of the Input Balance pot to ground and set the pot for zero voltage. Do not touch this control again until the adjustment is completed. Connect a 1K resistor across the input terminals.

Finally adjust the input offset trimmer (see layout drawing) until the meter on the panel reads zero. The "Input Polarity" switch may be switched back and forth to facilitate this adjustment. The meter will normally fluctuate somewhat with the 1K resistor across the input, but it is not difficult to set the average reading to zero.

Switch Maintenance

After a year or more of operation, some trouble may be experienced with build-up of an insulating film of dirt, oil and oxidation products on the contacts of the Range Switch, S_1.

The symptom of this trouble is drift of the meter zero setting on the low current ranges when the Function Selector is in the "input balance" or "operate" position. Normally the meter will fluctuate slightly on the low current ranges due to input circuit noise but there should be no observable drift in its average position. When the switch problem occurs, the average meter reading will not remain at zero and, in some cases the meter cannot be zeroed at all.

If these difficulties are encountered, the first thing to do is remove any external connection from the input. If the trouble ceases, the instrument is not at fault and the

external circuit should be examined for excessive leakage currents, shorts to ground, etc. If the symptoms remain with no input connection, however, the switch probably needs cleaning.

The choice of a cleaning agent is very important. Chlorinated hydrocarbons such as carbon tet and its so-called non-toxic replacements, acetone and many other common solvents, should be avoided because they will attack the polystyrene capacitors mounted on the switch. Contact cleaner-lubricants of the type used on TV tuner contacts should also be avoided because their residual lubricating film will create leakage paths which will destroy the accuracy of the instrument. Ethyl alcohol may be used safely but "MS-230 Contact RE-NU," manufactured by Miller-Stephenson Chemical Co., Inc., has been found to be far more effective and is highly recommended.

The switch should be worked vigorously while a stream of the cleaning solvent is directed at the contacts of each section in turn. Particular attention should be paid to sections 5 and 6.

Although it would appear that an enclosed switch would be preferable, one cannot be used because the molded bodies of such switches provide leakage paths between the terminals which could cause intolerable errors in an instrument which is so highly accurate at low currents.

Repairs

Every effort has been made in the preparation of this manual to provide competent personnel with sufficient information to keep the instrument in good operating condition. If problems arise, however, which cannot be solved in the field, the factory should be contacted for advice.

Repairs Under Guarantee

The Model 1000 Current Integrator is guaranteed to perform within specifications for one year from the date of purchase. Any required repairs not necessitated by abuse will be made free of charge.

Important: Do not return any unit without first contacting the factory for shipping instructions.

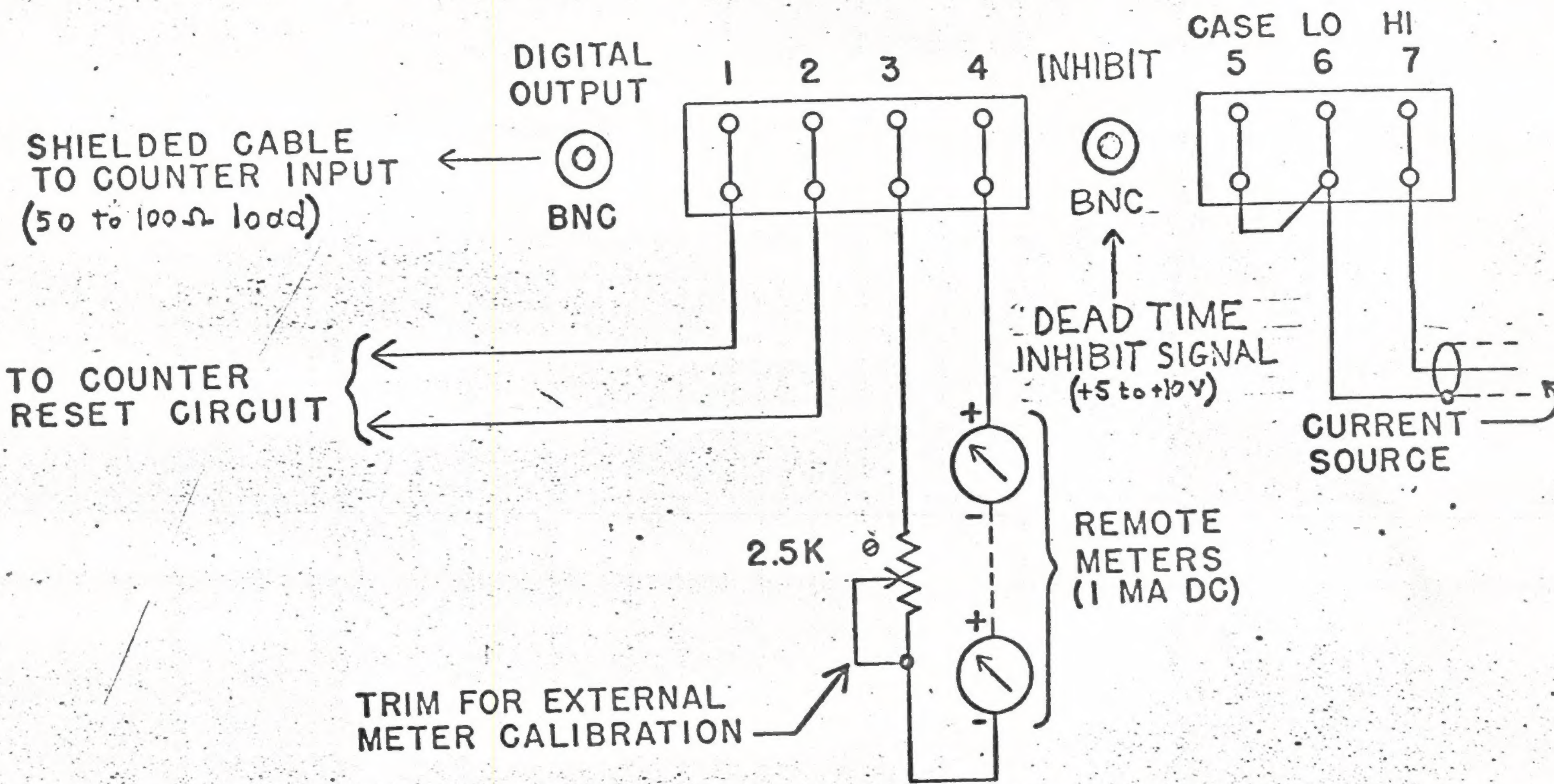

FIG. 1 - EXTERNAL CONNECTIONS USING REAR TERMINAL STRIP.

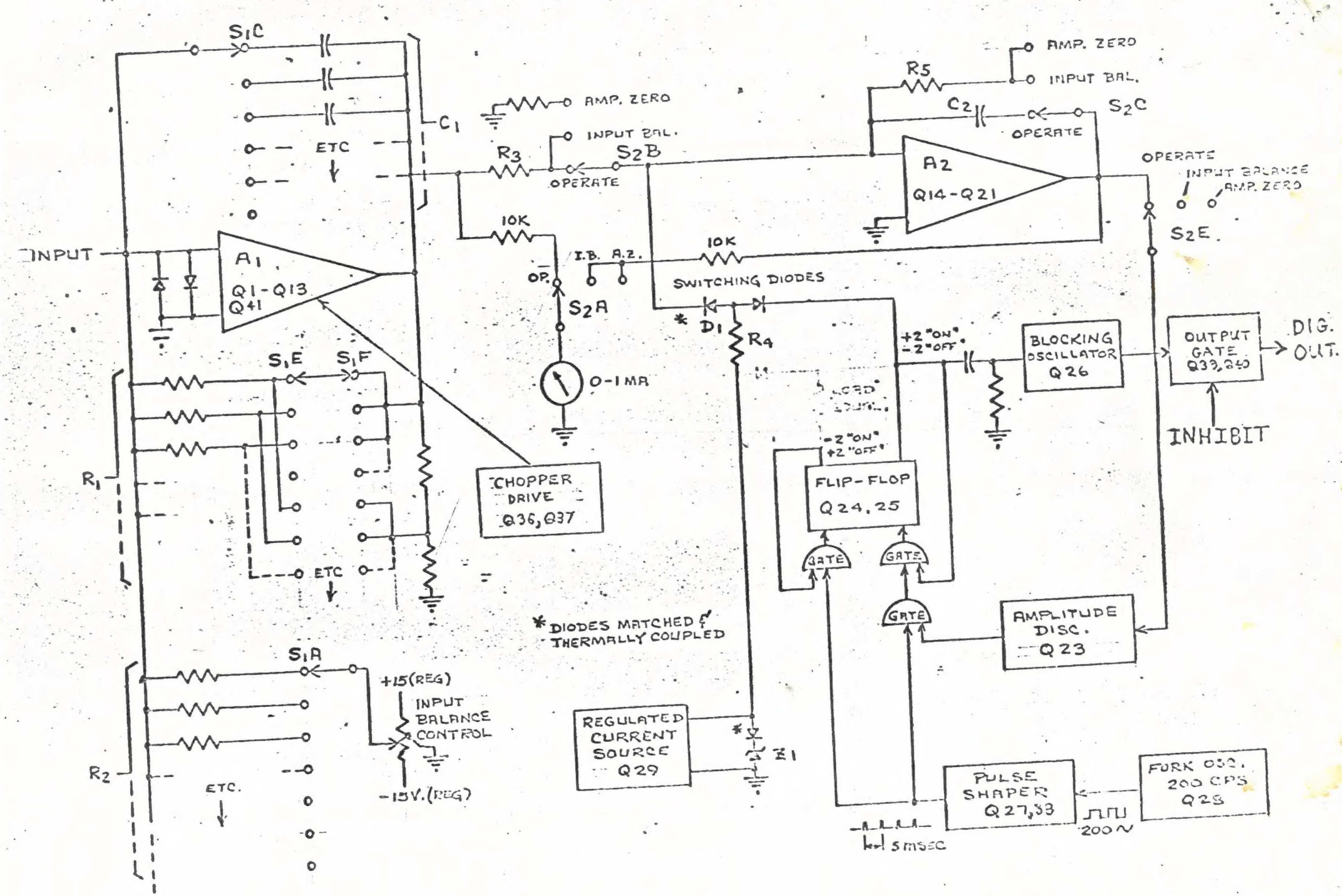

FIG. 2 - MODEL 1000 CURRENT INTEGRATOR
SIMPLIFIED BLOCK DIAGRAM